SHAPE MEMORY ALLOY HEAT ENGINES AND ENERGY HARVESTING SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 61/447,317; U.S. Provisional Application No. 61/447,315; U.S. Provisional Application No. 61/447,328; U.S. Provisional Application No. 61/447,321; U.S. Provisional Application No. 61/447,307; and U.S. Provisional Application No. 61/447,324; all filed Feb. 28, 2011. All of which are hereby incorporated by reference in their entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made with U.S. Government support under ARPA-E Contract number DE-AR0000040, awarded by the Department of Energy. The U.S. Government may have certain rights in this invention.

TECHNICAL FIELD

[0003] The present invention generally relates to energy harvesting systems, and more specifically, to energy harvesting systems using shape-memory alloy heat engines.

BACKGROUND OF THE INVENTION

[0004] Thermal energy may be produced by industrial, assembly, and manufacturing processes. Automobiles, small equipment, and heavy equipment also produce thermal energy. Some of this thermal energy is waste heat, which is heat for which no useful application is found or planned, and is generally a waste by-product. Waste heat may be expelled to the atmosphere. The burning of transport fuels also contributes to waste heat.

SUMMARY OF THE INVENTION

[0005] An energy harvesting system in thermal communication with a hot region and a cold region is provided. The energy harvesting system includes a hot end heat engine in thermal communication with the hot region, a cold end heat engine in thermal communication with the cold region, and an intermediate heat engine disposed between the hot end heat engine and the cold end heat engine.

[0006] The hot end heat engine includes: at least two rotatable pulleys; a timing cable disposed about a portion of the at least two rotatable pulleys and defining a timing pulley ratio; and a hot end shape memory alloy (SMA) element disposed about the at least two rotatable pulleys and defining an SMA pulley ratio different than the timing pulley ratio. The hot end SMA element has a hot side and a cold side, and the hot side of the hot end SMA element is directly in thermal communication with the hot region.

[0007] The cold end heat engine includes: at least two rotatable pulleys; a timing cable disposed about a portion of the at least two rotatable pulleys and defining a timing pulley ratio; and a cold end SMA element disposed about the at least two rotatable pulleys and defining an SMA pulley ratio different than the timing pulley ratio. The cold end SMA element has a hot side and a cold side, and the cold side of the cold end SMA element is directly in thermal communication with the cold region.

[0008] The intermediate heat engine includes: at least two rotatable pulleys; a timing cable disposed about a portion of the at least two rotatable pulleys and defining a timing pulley ratio; and an intermediate SMA element disposed about the at least two rotatable pulleys and defining an SMA pulley ratio different than the timing pulley ratio. The intermediate SMA element has a hot side and a cold side. The hot side of the intermediate SMA element is in thermal communication with the cold side of the hot end SMA element and the cold side of the intermediate SMA element is in thermal communication with the hot side of the cold end SMA element.

[0009] The above features and advantages and other features and advantages of the present invention are readily apparent from the following detailed description of the best modes for carrying out the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is a schematic diagram of an energy harvesting system including a heat engine;

[0011] FIG. **2** is a schematic side view of the heat engine of FIG. **1**;

[0012] FIG. **3** is a schematic side view of another heat engine usable with the energy harvesting system of FIG. **1**;

[0013] FIG. **4** is a schematic graphical representation of a work diagram for a heat engine, such as those shown in either FIG. **2** or FIG. **3**;

[0014] FIG. **5**A is a schematic, fragmentary cross-sectional view of a shape memory alloy (SMA) working element form having parallel strands of thin-wire SMA;

[0015] FIG. **5**B is a schematic, fragmentary cross-sectional view of another SMA working element form having parallel strands of SMA partially embedded within a matrix;

[0016] FIG. **5**C is a schematic, fragmentary cross-sectional view of a composite SMA working element built from individual units similar to those shown in FIG. **5**B;

[0017] FIG. **6**A is a schematic, plan view of a spring-based SMA working element having a fiber core within the spring coil;

[0018] FIG. **6**B is a schematic, plan view of another spring-based SMA working element having two springs and a fiber core within the spring coils;

[0019] FIG. **6**C is a schematic, plan view of another spring-based SMA working element having interleaved springs with two fiber cores within the spring coils;

[0020] FIG. **7**A is a schematic, side view of a braided SMA working element and an inset close-up view of the same;

[0021] FIG. **7**B is a schematic, side view of a woven mesh SMA working element and an inset close-up view of the same;

[0022] FIG. **8**A is a schematic, isometric view of another heat engine having a multi-planar loop;

[0023] FIG. **8**B is a schematic, isometric view of another heat engine having a multi-planar loop with a three-dimensional guide;

[0024] FIG. **9** is a schematic, illustration or diagram of an energy harvesting system having three, cascaded heat engines, in which the cold side of one heat engine acts as the hot side of another;

[0025] FIG. **10** is a schematic, side view of an energy harvesting system having a longitudinal heat engine;

[0026] FIG. **11**A is a schematic, isometric view of an energy harvesting system having a plurality of heat engines